

Precision and Smart Metrology

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A large, bold, black opening quotation mark.

If you measure

“Do it with Utmost Care”

and

“Remember the Measuring Errors”

A large, bold, black closing quotation mark.

- Anonymous

The Science of Precision Measurement

“METRO” & “LOGY” are Greek Words

Meaning

“Measurement” and “Science”

Respectively

Metrology Started in Ancient Egypt in

2750 BC

First Unit of Length Was **Cubit**

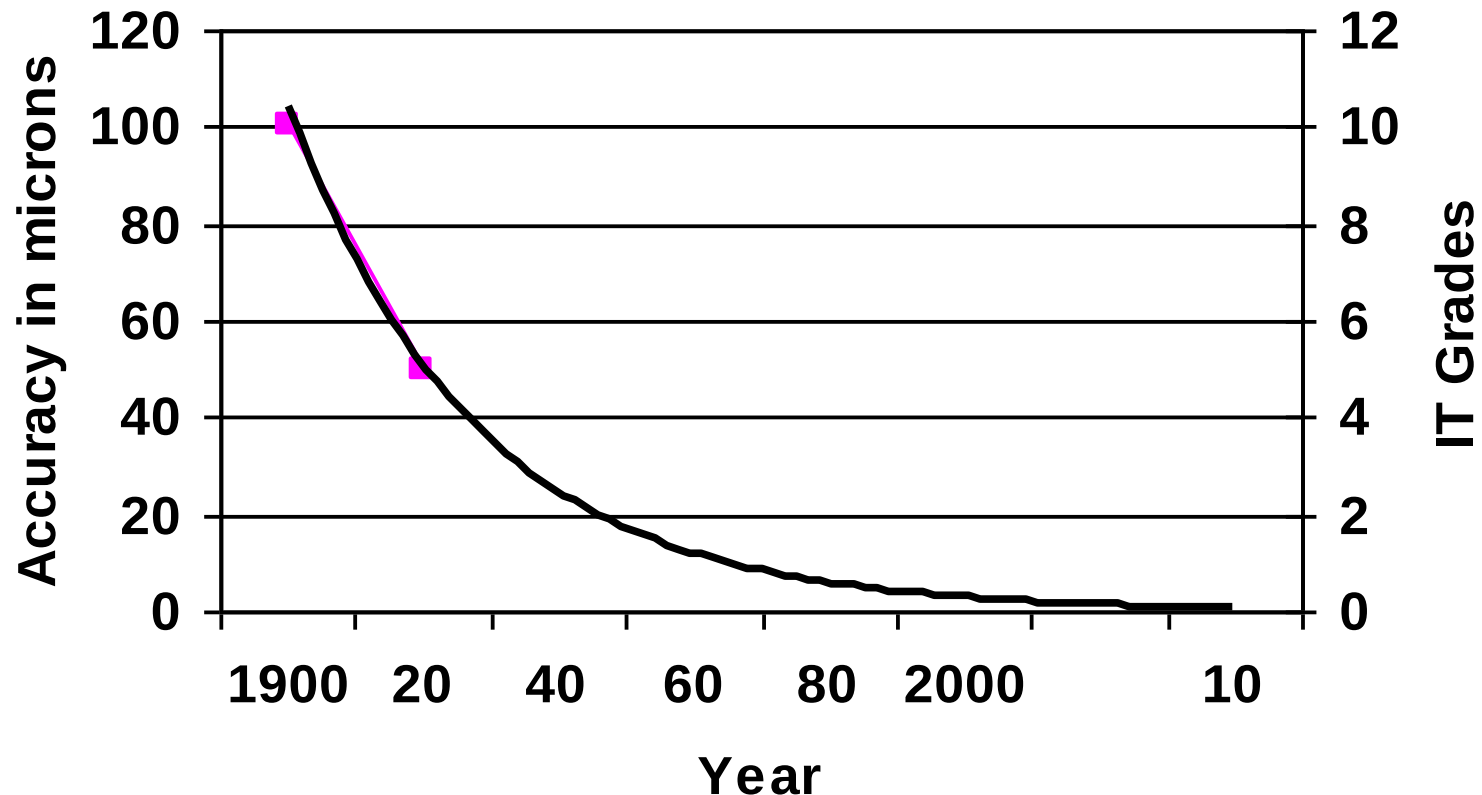
Cubit - Length of the Reigning

Pharaoh's Forearm

Journey towards Precision

- Started in 1775 with Wilkinson machining a $\phi 1800$ mm bore to 1 mm accuracy
- Today conventional precision machining is being carried out to dimensional accuracies of $1 \mu\text{m}$ on 100 mm length

Dimensional Accuracies since 1900



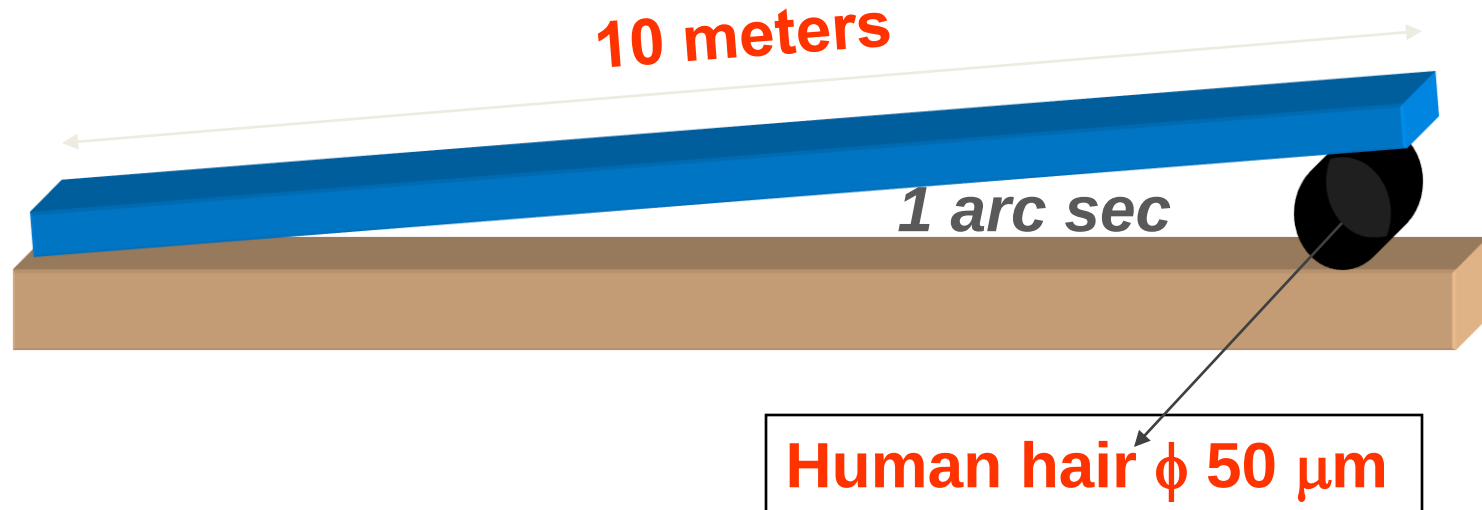
What is 1 μ m



 1 μ m

1nm=1/1000 μ m

What is 1 arc sec



The Goal of Metrology

- **Accept good products**
- **Reject bad products**
- **Better to reject few good ones
than to accept a few bad ones**

Classification of Metrology

- **Dimensional Metrology**
 - **Surface Metrology**
 - **Co-Ordinate Metrology**
 - **Mass Metrology**
 - **Force Metrology**
- and So on**

BASIC TERMINOLOGIES

Basic Terminologies

RESOLUTION (of a displaying device)

Smallest value that can be indicated by the displaying device.

or

Smallest difference between indications of a displaying device that can be meaningfully distinguished



Basic Terminologies

ACCURACY

Closeness of agreement between the result of measurement and the true value of the measurand.

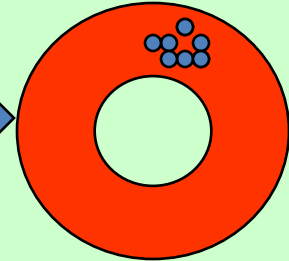
PRECISION

Closeness of agreement between the results of successive measurements of the same value of a quantity carried out under identical conditions at short intervals of time.

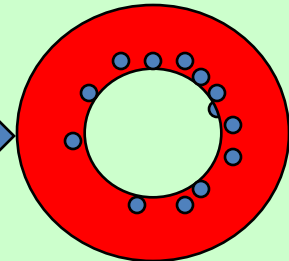
(Precision is also called Repeatability)

Graphic Distinction Between Accuracy and Precision

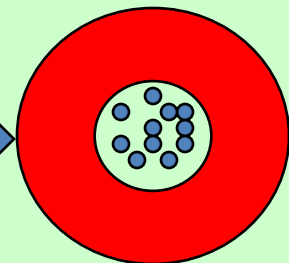
Precise but not Accurate



Accurate but not Precise



Precise and Accurate



Basic Terminologies

REPRODUCIBILITY

Closeness of agreement between corrected results of measurements of the same value of a quantity when the measurements are made under different conditions.

RELIABILITY

The ability of an item to perform a required function under stated conditions for a stated period of time.

Basic Terminologies



TRACEABILITY

The concept of establishing valid calibration of a measuring standard or instrument by step-by-step comparison with better standards upto an accepted national or international standard.

Measurement Standard

Material measure or physical property which defines or reproduces the unit of measurement of a base or derived quantity.

Types of Measurement Standard

- **FUNDAMENTAL OR ABSOLUTE STANDARD**
- **INTERNATIONAL STANDARD**
- **NATIONAL OR PRIMARY STANDARD**
- **REFERENCE STANDARD**
- **SECONDARY STANDARD**
- **WORKING OR STANDARD**

Hierarchy of Traceability

Primary Standard of Length (Metre)
Established by Interferometry



Secondary Standard of Length
Verified by Interferometry



Grade "00" Slip gauges Calibration Grade
Verified by Interferometry



Grade "0" & "1" Slip gauges
Verified by high magnification comparator



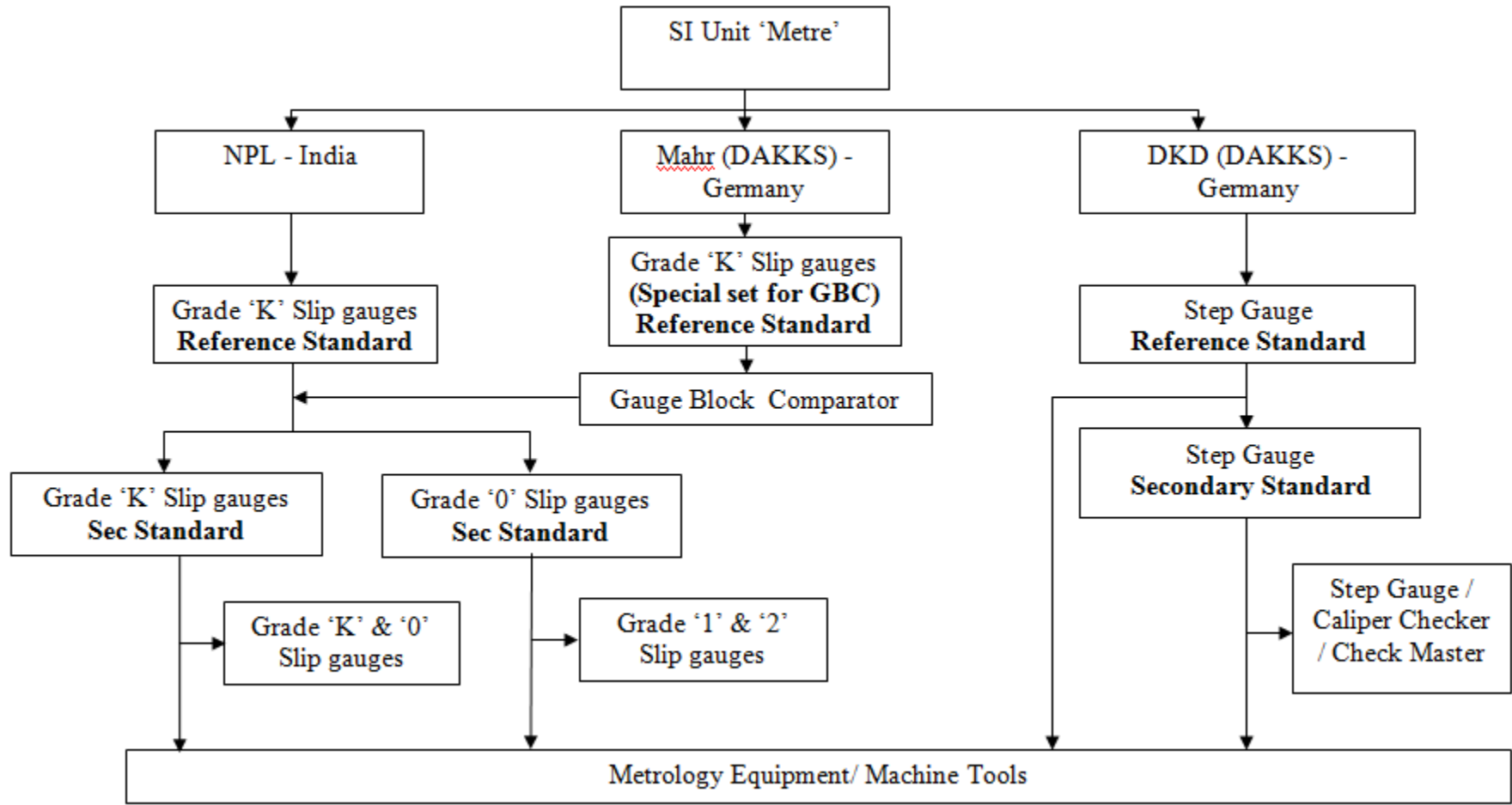
Grade "2" Slip gauges
Verified by high magnification comparator



Work piece
Verified by suitable gauging practice

The metre is defined
as the length of the
path travelled by light
in a vacuum in
 $1/299\,792\,458$ second

Length Traceability at CMTI



Factors effecting the Accuracy of Measurements



S

Factors affecting the Standard

W

Factors affecting the Work-piece

I

Factors affecting the Measuring Instruments

P

Factors affecting the Person

E

Factors affecting the Environment

Factors affecting the Accuracy of Measurements



Environmental Effects:

- Room Temperature
- Part Temperature Stabilization
- Temperature Variation
- Humidity
- Vibration Level
- Dust Level
- Air Flow
- Lighting

Precision Metrology Laboratory at CMTI

NABL Accredited Dimensional Metrology Lab

Lab conforms to ISO/ IEC 17025:2005

Measurement of Dimension, Form, Surface Texture and Gear Parameters



Temp: 20
± 0.5°C

Vibration
: < 0.2
µm

Noise:
<60 dB

Clean
Room
Class:
10,000

*“India’s one of the kind
metrology lab that is housed
6m below ground”*

Dimensional Metrology at CMTI



Ultra Precision Co-ordinate Measuring Machine



Co-ordinate Measuring Machine



Gauge Block Interferometer

Surface Metrology at CMTI



Form profiler



Roughness Tester

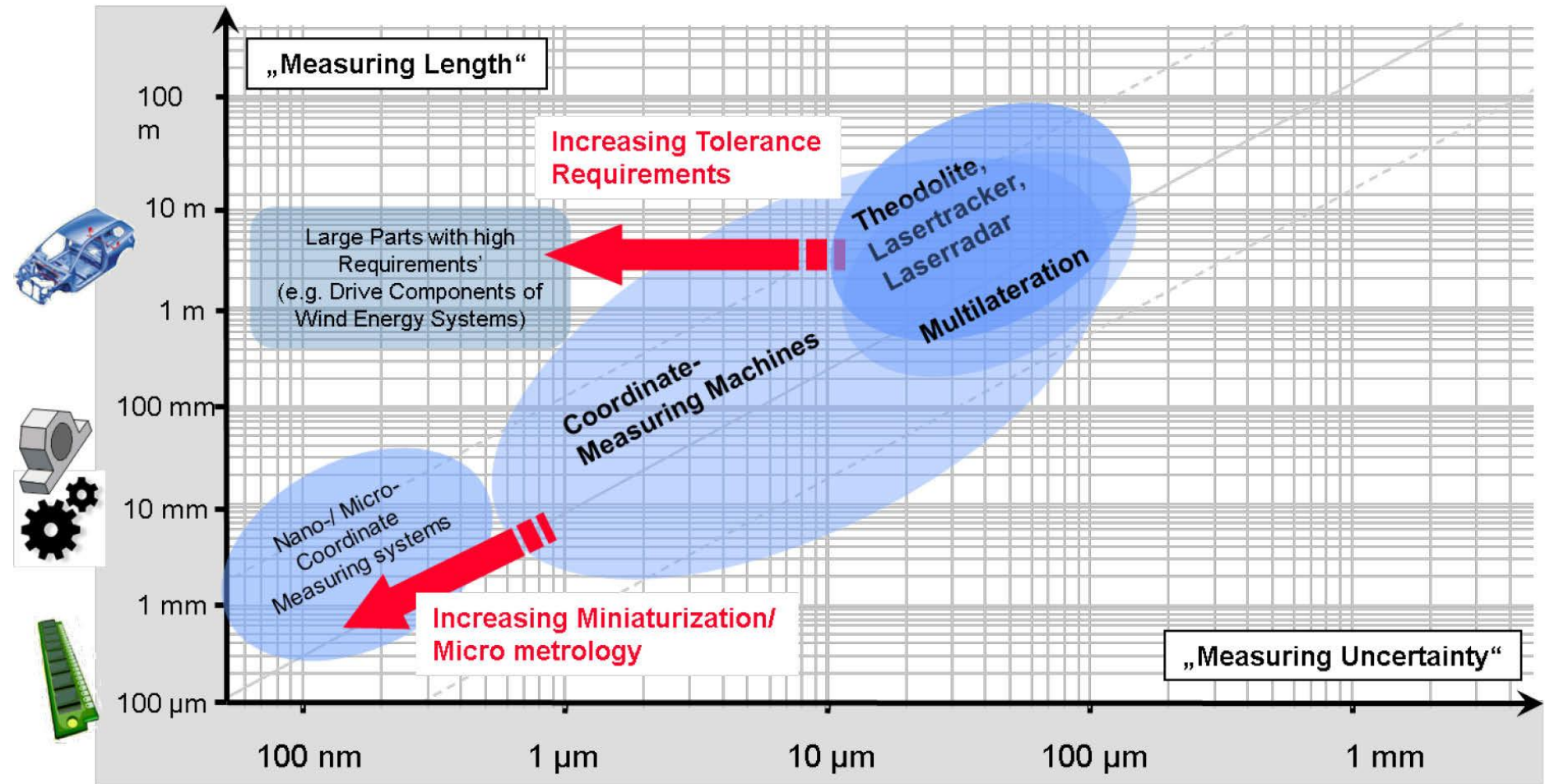


Flatness interferometer



Optical Profiler

Trends of Accuracy/ Uncertainty in Length Measurement



Metrology Artefacts



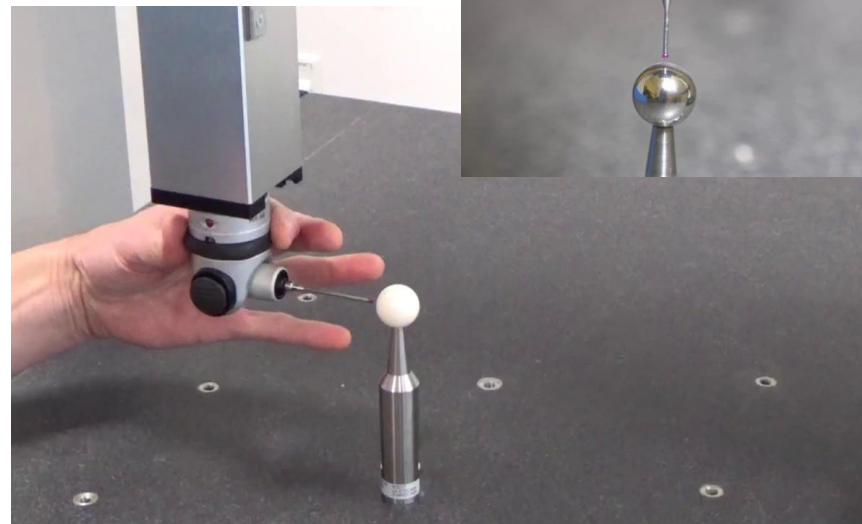
OPTICAL FLAT



GLASS HEMISPHERE



MASTER CYLINDER

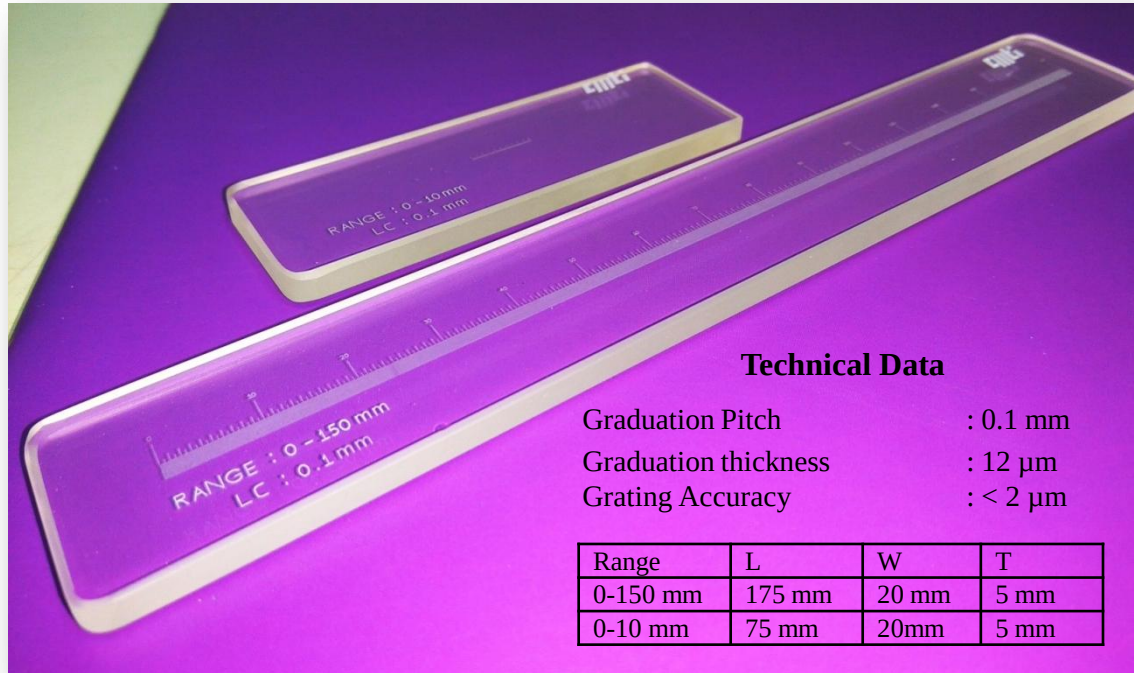


COORDINATE MEASURING MACHINE (CMM) AND MASTER SPHERE

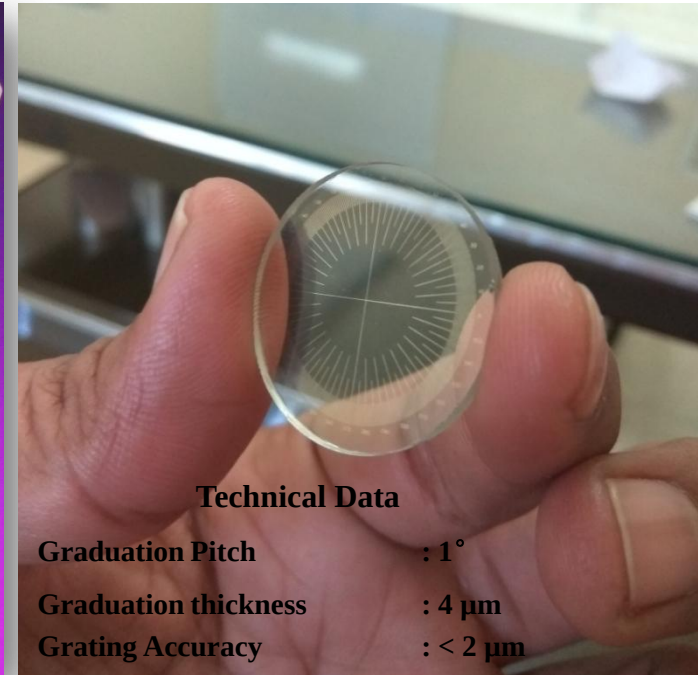
Current Status: In the country most of these artefacts (>90 %) are being imported

Efforts of CMTI in development of Indigenous Metrology Artefacts

High Precision Optical Standard Glass Scales



Linear Standard Glass Scales

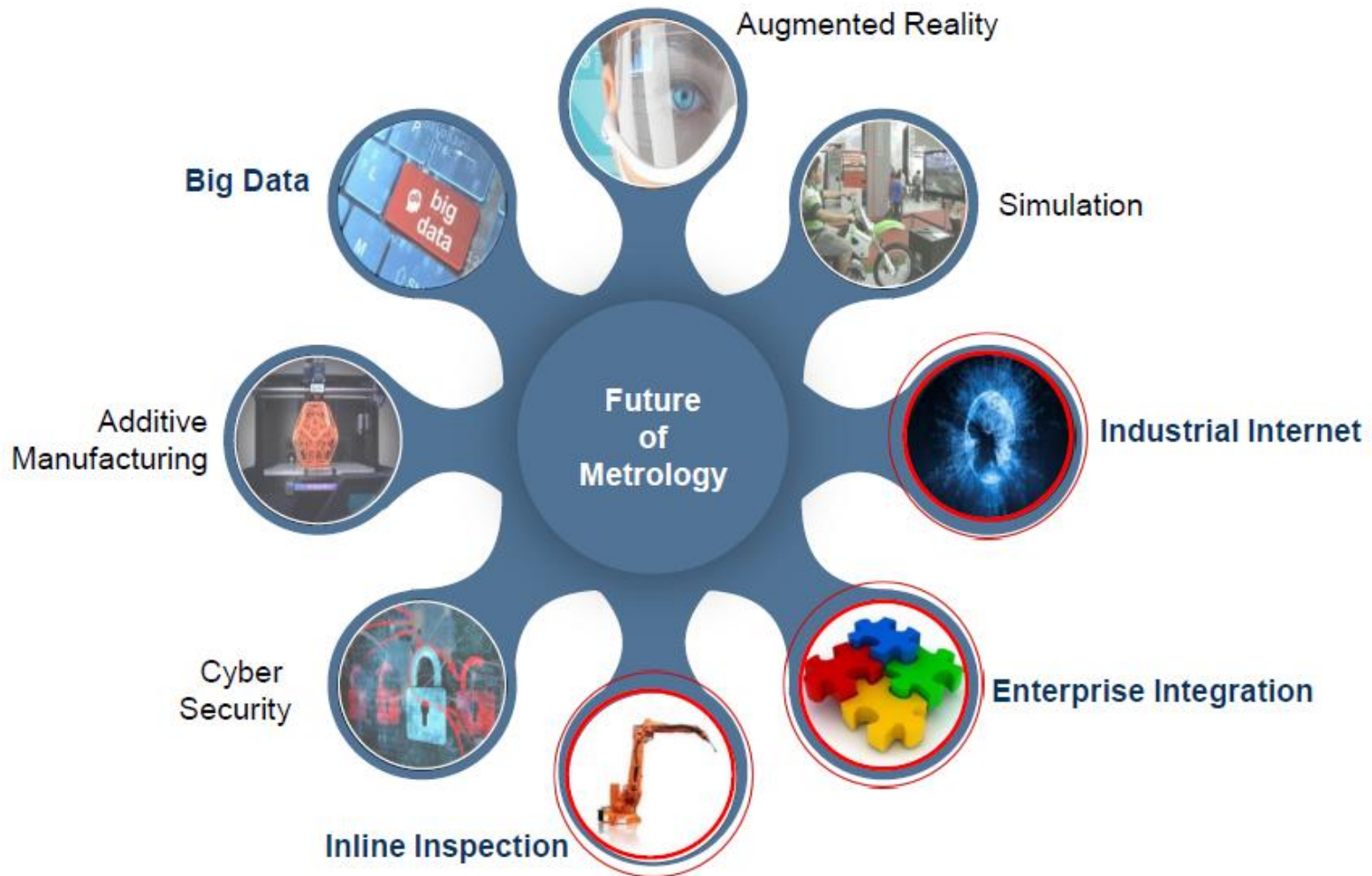


Angular Standard Glass Scale

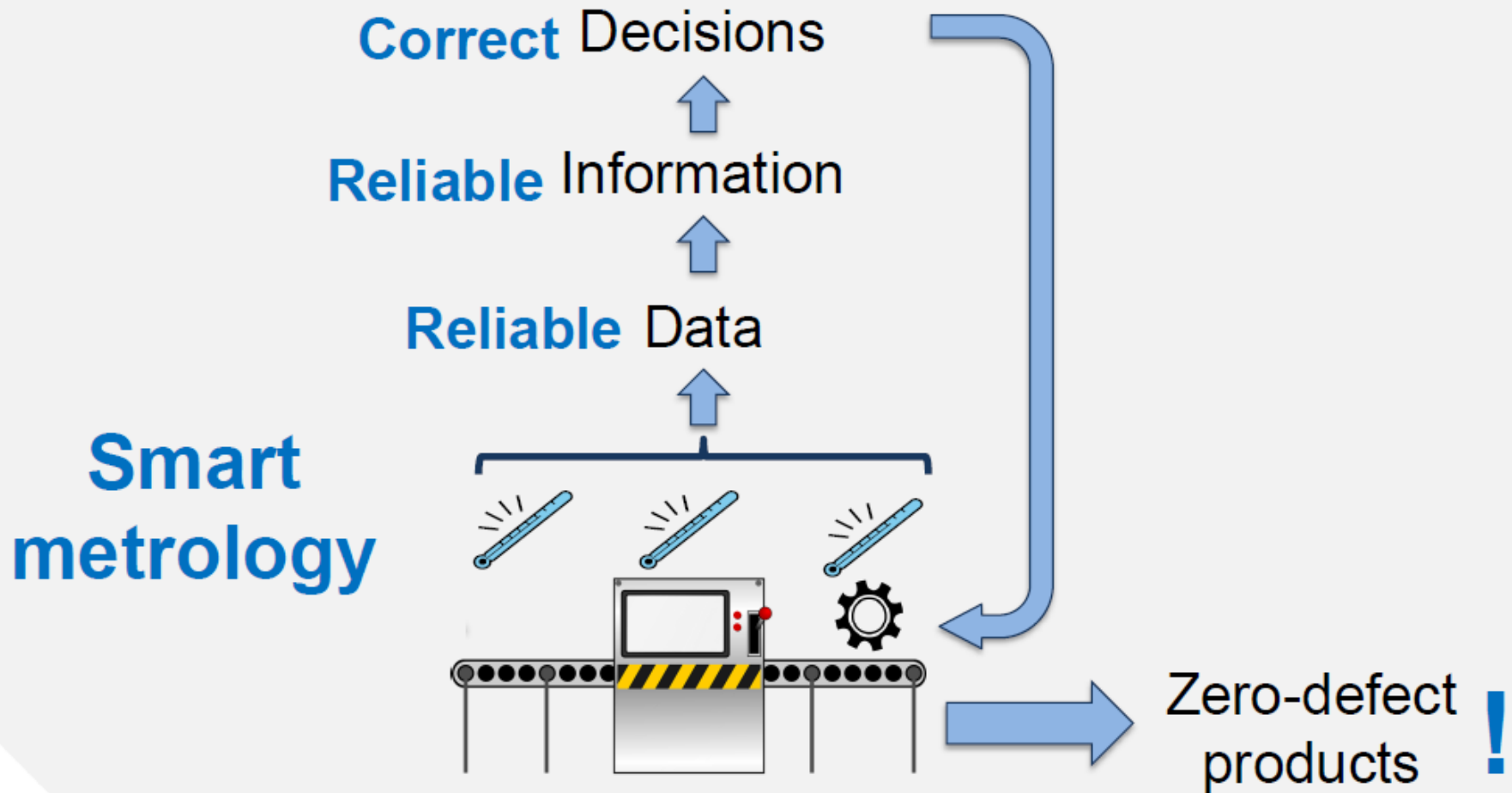
In-house facility used:

1. Femtosecond laser micromachining system
2. Confocal Microscope
3. Ultra Precision CMM

Transformative Forces Reshaping the Future of Metrology



The need for Smart Metrology



Smart Metrology Challenges

Product flow

- Measurement time
- Accessibility of features
- Motion and handling

Environment

- Temperature
- Humidity
- Vibrations, contamination

Diversity

- Multiple features per product
- Variation between products

Data handling

- Task-specific uncertainty,
- Numerical accuracy and Data integrity
- Data fusion from multiple sensors

Factors to consider in adapting Smart Metrology

INLINE
METROLOGY



NON-CONTACT:
OPTICAL AND LASER
SYSTEMS



ROBOTS

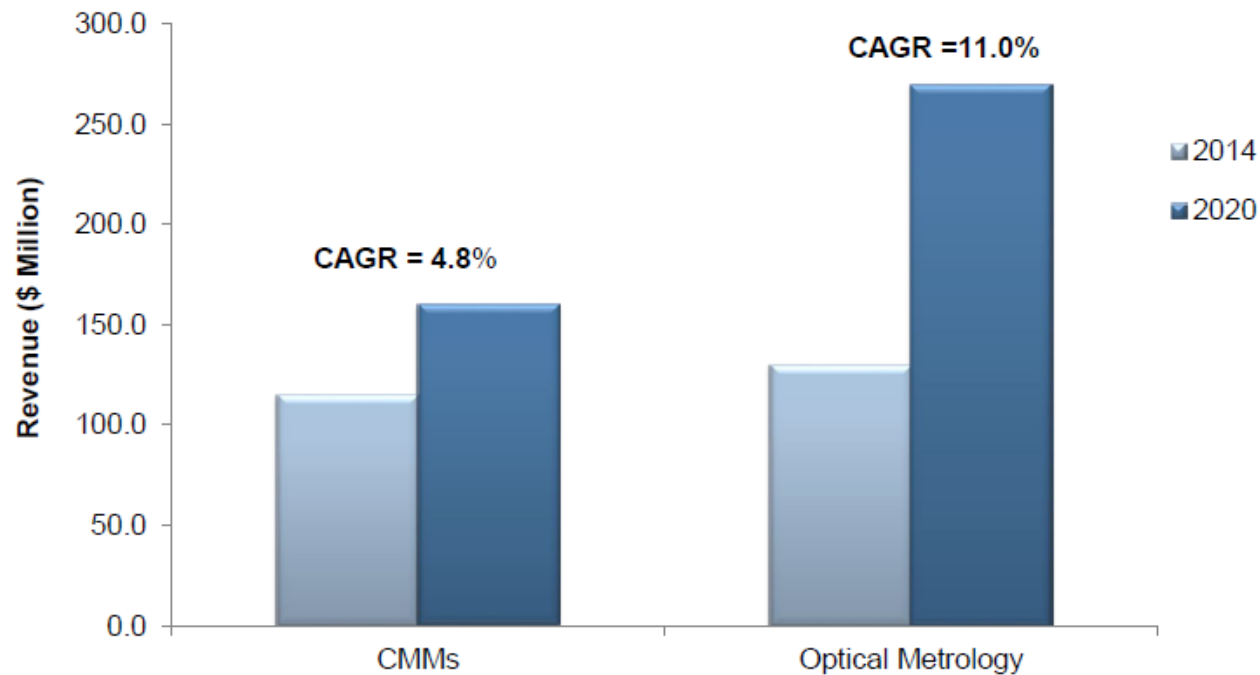


Inline Metrology

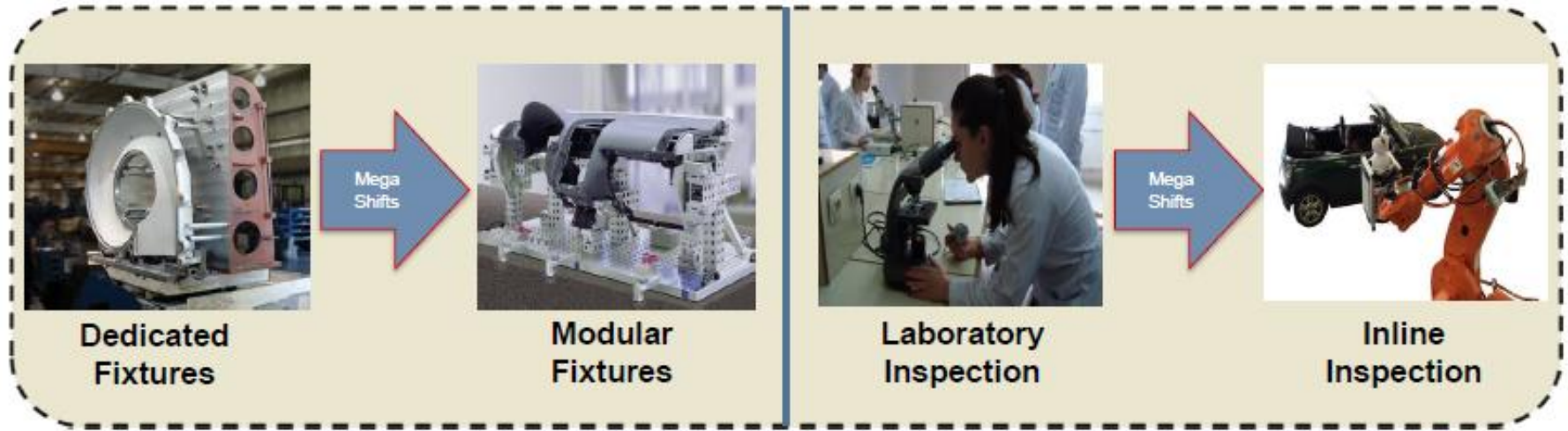
Inline Metrology—Market Size and Forecasts

Speed, accuracy, and flexibility are key attributes that enable optical scanners to replace traditional CMMs.

Global Inline Metrology Market Revenue by Key Technologies: 2014 and 2020



Mega Shifts



New Mega Shifts

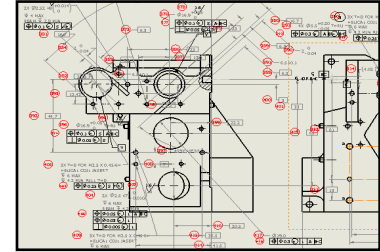


Increased Penetration of Optical Metrology

Smart Metrology Lab



Manual Inspection
Data



Auto Ballooning



CMM Data



Wireless Measuring
Instruments Data



Cloud / Server

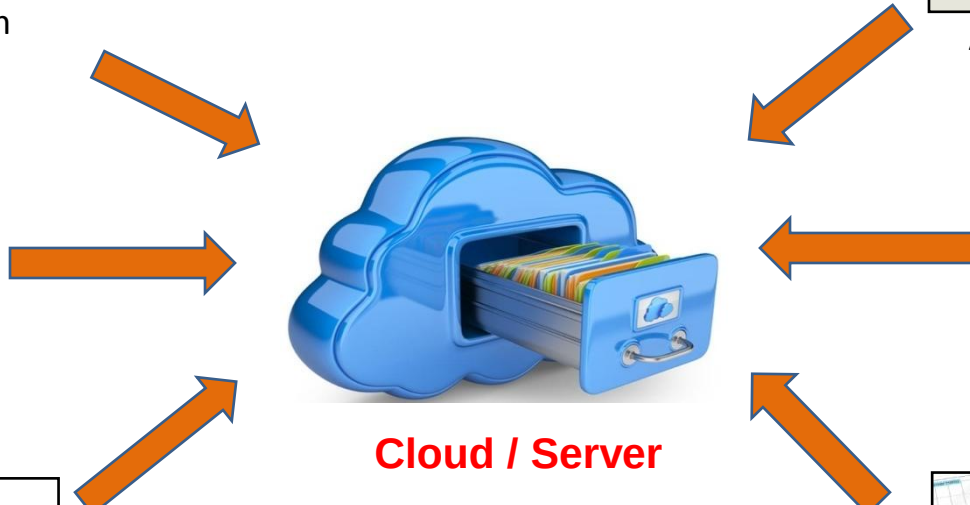
Measurement - Friday, November 30, 2018 12:16:18 PM (15 Measured values)

/SLOOM/1331-2/Angle 5	Angle 5	
/SLOOM/1331-2/Angle 15	Angle 15	
/SLOOM/1331-2/Diameter ø 40	Diameter ø 40	40.03
/SLOOM/1331-2/Diameter ø 46	Diameter ø 46	46
/SLOOM/1331-2/Diameter ø 48	Diameter ø 48	48
/SLOOM/1331-2/Diameter ø 52	Diameter ø 52	52.3
/SLOOM/1331-2/Diameter ø 57.5	Diameter ø 57.5	57.495
/SLOOM/1331-2/Diameter ø 60	Diameter ø 60	60.1
/SLOOM/1331-2/Diameter ø 126	Diameter ø 126	126.1
/SLOOM/1331-2/Length 4	Length 4	4
/SLOOM/1331-2/Length 10	Length 10	10
/SLOOM/1331-2/Length 12	Length 12	11.995
/SLOOM/1331-2/Length 45	Length 45	45.4
/SLOOM/1331-2/Diameter1 ø 40	Diameter1 ø 40	39.976
/SLOOM/1331-2/Diameter2 ø 40	Diameter2 ø 40	40.027

Inspection Reports



Quality Control



Smart Metrology Lab

Smart Inspection

- Automatic generation of Inspection Data sheet
- Wireless exchange of inspection data

Smart Data Management

- Integration across
 - Inline
 - Manual
 - CMM Inspection
- Real Time Data Visualisation

Smart Quality Management

- Improved Traceability
- Statistical Process control data (Cp,Cpk)
- Customized Inspection reports

Smart Inspection

Smart Inspection Facility encompassing

- Smart Measuring Instruments
- Smart Quality Monitoring
- Smart Process Monitoring



Smart Inspection Lab

A smart inspection and data management application for digital metrology is setup.

The application would collect, store, present digital data from Smart Bluetooth enabled instruments and data from other instruments/ equipments / gauges and CMM.

Data analytics such as Cp, Cpk are also performed to provide process capability information.

SMART Automated Inspection System Developed by CMTI

Auto-Correction Feedback



**Multi Gauging System
for Sabot**



**Multi Gauging System
for Penetrator**



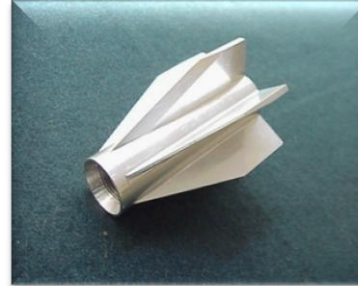
**Multi Gauging System
for Tail Piece**



SABOT



PENETRATOR



TAIL PIECE

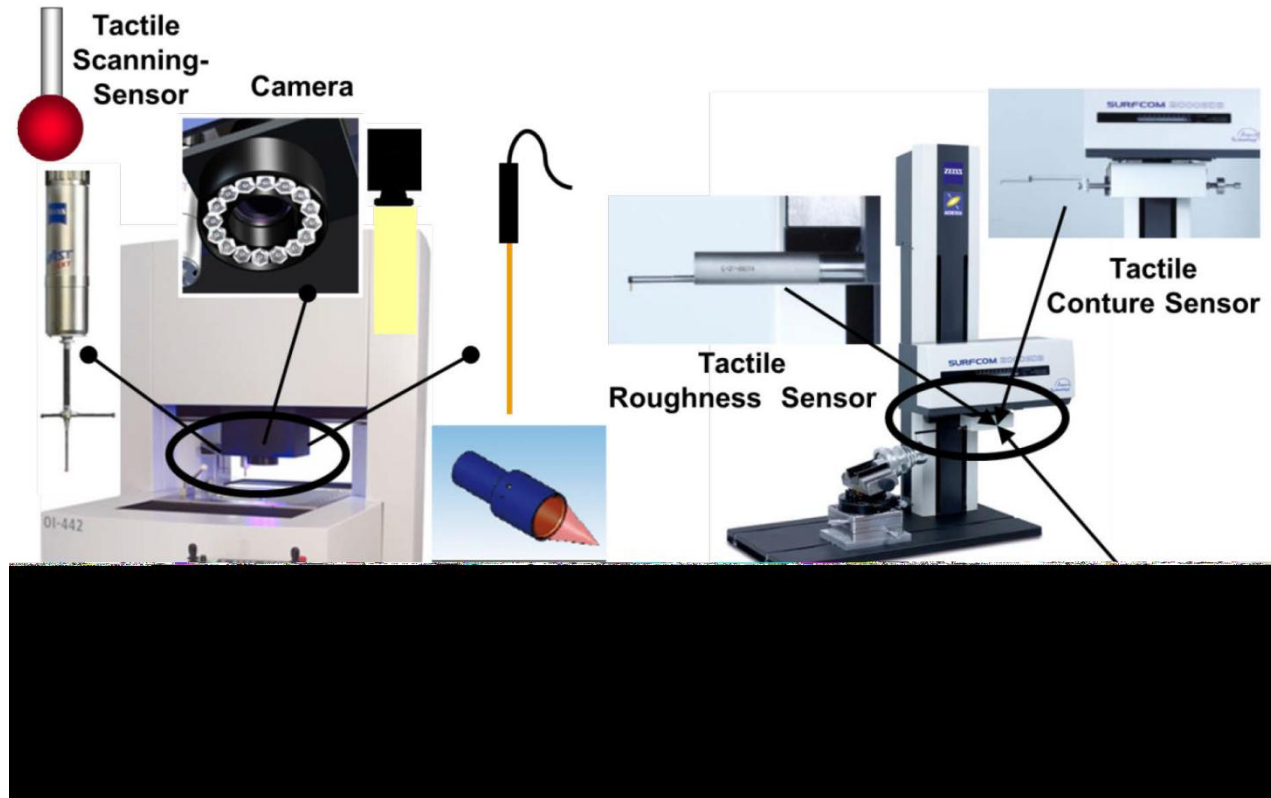
Highlights:

- Automated Measurement of Internal Thread Parameters, Form Errors and Dimensions
- 18 Parameters measured and documented in just over 3 minutes

The system was developed for comparing manufactured dimensions of the components with that of the designed dimensions, record the deviations and indicate whether the component can be accepted, rejected or needs rework.

- Automatic gauging significantly cuts down the inspection time
- Eliminates human measurement error
- Measured data is stored and accessed from the PC for statistical analysis.
- Online correction for the dimensional variation by automatically feeding the result of inspection to CNC system

Multi Sensor Implementations



Parallel Sensor Implementation
on a Co-ordinate Measuring
Machine

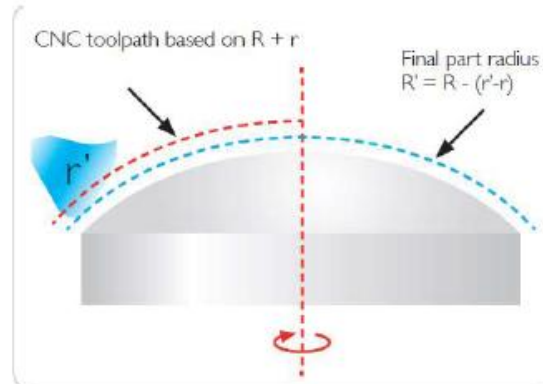
Changeable Sensor
Implementation on Surface
Texture Measuring Device

Automated Integrations

Faster metrology due to the automated integration of a CMM into material flow by Robot loading.

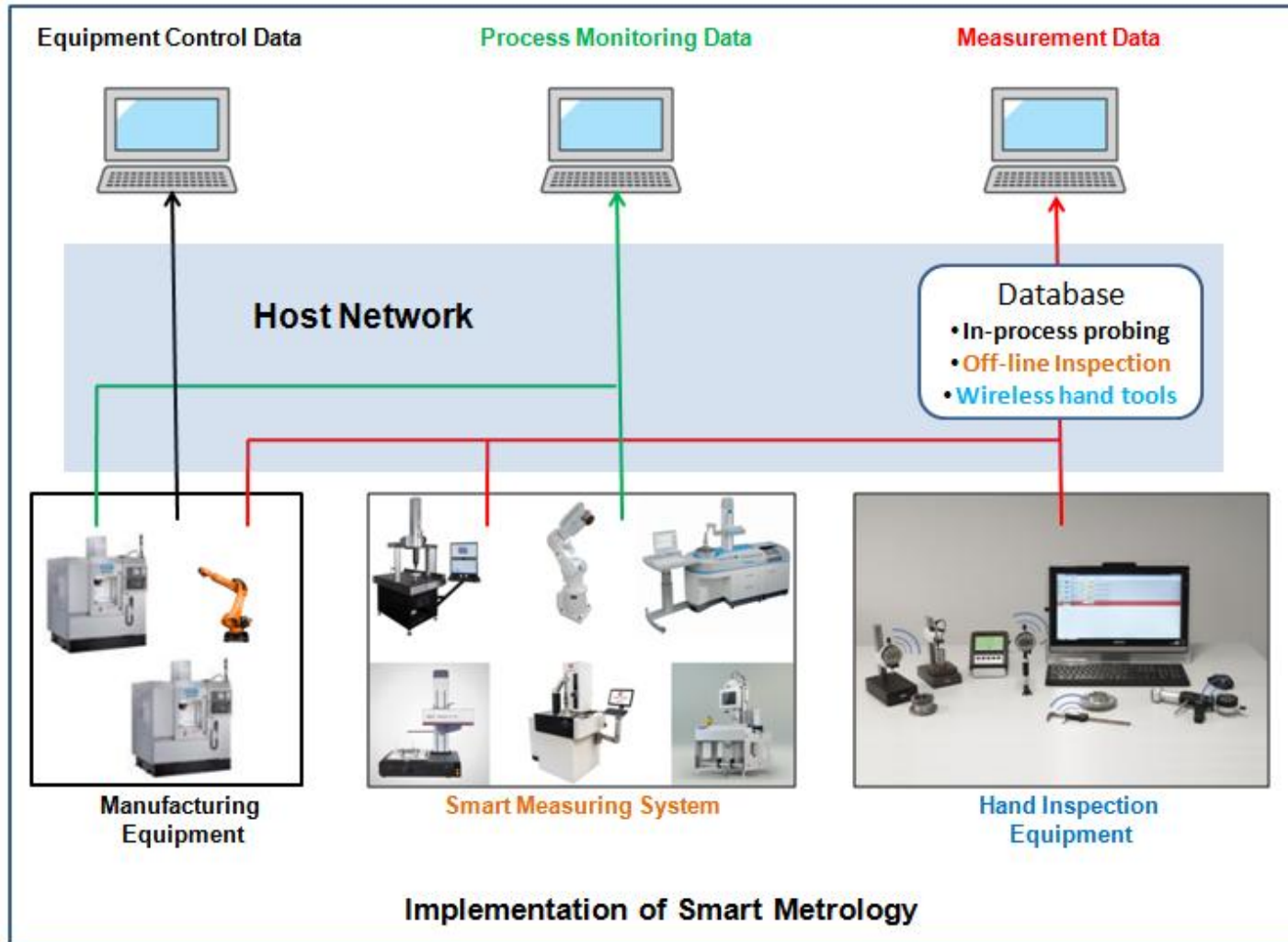


Process Correction Solutions



Measurement of X-offset / Tool Radius as well as automatic quick correction for it from direct measurement of a production asphere.

Smart Metrology Cell



Digitization

Digitization of Industrial Measurement Throughout the Supply Chain

Revenues from ERP software will surpass the hardware revenues over the next 5-8 years.

